LOCKHEED TECHNICAL NOTE

HUNTSVILLE RESEARCH & ENGINEERING CENTER

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Title: SUMMARY OF ENGINE CHARACTERISTICS CONSIDERED IN PLUME DEFINITION STUDY

FOREWORD

This document discusses work performed by Lockheed's Huntsville Research & Engineering Center while under subcontract to Northrop Nortronics (NSL PO 5-09287) for the Aero-Astrodynamic Laboratory of Marshall Space Flight Center (MSFC), Contract NAS8-20082. This task was conducted in conjunction with tasks being performed in response to the requirements of Appendix B-1, Schedule Order Nos. B-104 and B-100.

This report presents general information on all engines for which exhaust plume characteristics are being determined in this task.

DISCUSSION

Exhaust plume characteristics for the RIE, R4D and AJ10-137 rocket engines are being generated for use in determining the effects of plume impingement on the S-IVB Orbital Workshop and associated bodies. Although these engines have been qualified for some time, their nominal operational characteristics are still subject to frequent modifications during the system design phase. Since the process of generating exhaust plume characteristics with real gas and chemistry effects is quite arduous, the calculation of plume data for each engine modification being considered would not be feasible. It is desirable, therefore, to establish a set of "nominal" operating conditions to be used in the generation of the final plume flowfield information. These nominal values are presented in this report.

The mixture ratio (O/F) distribution in the combustion chamber of a rocket motor can produce a significant influence on the gas dynamic properties of the resulting plume. Consequently, the O/F distribution should be evaluated and considered when adequate data are available. An estimate of the O/F distribution can sometimes be made based upon the injector orifice patterns. Information concerning the injector patterns of the three engines being investigated is included in Tables 1 through 4. This information was used, where applicable, to estimate O/F distributions.

A uniform O/F ratio is assumed in this study for the R1E engine which is used in the Auxiliary Propulsion System of the Orbital Workshop. This assumption is based on a consideration of the operating mode of the engine and the injector pattern. The R1E engine will be operated primarily in a short-duration mode which results in the transient operating conditions being predominant. The injector pattern that is utilized is composed of a single impinging stream of oxidizer and fuel. Although a non-uniform O/F distribution will probably exist, no realistic means are available for determining such a distribution analytically. Experimental data are required to define the actual O/F distribution.

On the basis of information currently available a set of nominal engine characteristics has been established for each engine and application. Various sources were consulted in compiling this information (References 1 through 7). In each case the engine characteristics selected represent the most common operating conditions for a given application. The engine manufacturers were consulted in each case for specific nozzle contour and engine operating conditions. The selected nominal engine characteristics are presented in Tables 1 through 4 and Figures 1 through 4. The information presented in the above tables and figures is being utilized as the nominal engine characteristics for the purpose of generating plume flowfield data.

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Attach: (1) References
(2) Tables 1 through 4
(3) Figures 1 through 4

REFERENCES

1. Chemical Propulsion Information Agency, "Liquid Propellant Engine Manual (U)," Publication No. 5. CONFIDENTIAL.

2. Aerojet General Corporation, "General Information Brochure on AJ10-137," Sacramento, Calif., January 1967.

3. Aerojet General Corporation, "Configuration, Thrust Chamber, Internal AJ10-137 60:1," Blueprint 085782, Sacramento, Calif.

4. Marquardt Corporation, "Information on Nozzle Contour for R1E Engine," May 1968.

5. Marquardt Corporation, "Information on Nozzle Contour for R4D Engine," May 1968.

6. Telephone Conversations with Mr. Henry Pohl, Small Engine Section, NASA Manned Space Flight Center, Houston, Texas.

7. Telephone Conversations with Mr. Ed Jacobs, Engine and Power Branch, Propulsion & Vehicle Engineering Laboratory, Marshall Space Flight Center, Huntsville, Ala.

Table 1

NOMINAL R1E ENGINE OPERATING CHARACTERISTICS FOR S-IVB AUXILIARY PROPULSION SYSTEM

Propellant

Oxidizer N_2O_4

Fuel CH_3NHNH_2
(Monomethylhydrazine)

Engine Parameters

$A/A^* = 40:1$

$D_{exit} = 2.62$ in.

$\Theta_{exit} = 8^o$

$P_C = 96.5$ psia

*$O/F = 1.6$

$\dot{m}_{total} = 0.083\ lb_m/sec$

Thrust (nominal) = $22\ lb_f$ (vac) $\pm 1\ lb_f$

$D_{chamber} = 0.94$ in.

Injector System – Single Fuel/Oxidizer Doublet

*A tolerance for the nominal O/F currently is not specified.

Nozzle Contour

X	R	
0.000	0.2068	Throat – Blend nozzle contour with throat using 0.25-inch radius of curvature. See Figure 1.
0.225	0.301	
0.385	0.395	
0.635	0.525	
0.885	0.641	
1.135	0.744	
1.385	0.837	
1.635	0.925	
1.885	0.998	
2.135	1.067	
2.385	1.128	
2.635	1.180	
2.885	1.228	
3.135	1.269	
3.385	1.308	Exit Plane

Table 2

NOMINAL R4D ENGINE OPERATING CHARACTERISTICS FOR LUNAR EXCURSION MODULE REACTION CONTROL SYSTEM APPLICATION

Propellant

Oxidizer N_2O_4

Fuel N_2H_4 50%, $(CH_3)_2NNH_2$ 50% } Aerozine-50

Note: The fuel for the LM application of the R4D will be changed to monomethyhydrazine in the near future.

Engine Parameters

$A/A^* = 40:1$

$D_{exit} = 5.46$ in.

$\Theta_{exit} = 8^o$

$P_C = 100$ psia

$O/F = 2.03 \pm 0.03$

$\dot{m}_{total} = 0.318\ lb_m/sec$

Thrust (nominal) = $100 \pm 5\ lb_f$ (vac)

$D_{chamber} = 1.77$ in.

Injector System — Eight fuel/oxidizer doublets with single igniter doublet in center of injector face. Fuel film cooling used on chamber and pre-igniter walls. The mixture ratio, O/F, varies across the injector face. An O/F distribution for the unreacted propellants was assumed based upon the injector orifice arrangement and is shown in Figure 4.

Nozzle Contour

X	R	
0.000	0.434	Throat — Blend nozzle
0.278	0.513	contour with throat using
0.474	0.635	0.527 radius of curvature.
0.812	0.832	See Figure 2.
1.339	1.106	
1.400	1.134	
1.866	1.349	
2.393	1.565	
2.920	1.762	
3.447	1.940	
3.974	2.101	
4.501	2.245	
5.028	2.372	
5.555	2.483	
6.082	2.583	
6.609	2.671	
6.984	2.730	Exit Plane

Table 3

NOMINAL R4D ENGINE OPERATING CHARACTERISTICS FOR COMMAND SERVICE MODULE REACTION CONTROL SYSTEM APPLICATION

Propellant

Oxidizer N_2O_4

Fuel $CH_3\ NHNH_2$
(Monomethylhydrazine)

Engine Parameters

$A/A^* = 40:0$

$D_{exit} = 5.46$ in.

$\Theta_{exit} = 8^o$

$P_C = 100$ psia

$O/F = 2.03 \pm 0.03$

$\dot{m}_{total} = 0.314\ lb_m/sec$

Thrust (nominal) $= 100 \pm 5\ lb_f$ (vac)

$D_{chamber} = 1.77$ in.

Injector System – Eight fuel/oxidizer doublets with single igniter doublet in center of injector face. Fuel film cooling used on chamber and pre-igniter walls. The mixture ratio, O/F, varies across the injector face. An O/F distribution for the unreacted propellants was assumed based upon the injector orifice arrangement and is shown in Figure 4.

Nozzle Contour

X	R	
0.000	0.434	Throat – Blend nozzle
0.278	0.513	contour with throat using
0.474	0.635	0.527 radius of curvature.
0.812	0.832	See Figure 2.
1.339	1.106	
1.400	1.134	
1.866	1.349	
2.393	1.565	
2.920	1.762	
3.447	1.940	
3.974	2.101	
4.501	2.245	
5.028	2.372	
5.555	2.483	
6.082	2.583	
6.609	2.671	
6.984	2.730	Exit Plane

Table 4

NOMINAL AJ10-137 ENGINE OPERATING CHARACTERISTICS FOR APOLLO SERVICE MODULE MAIN PROPULSION SYSTEM APPLICATION

Propellant

Oxidizer N_2O_4

Fuel: N_2H_4 50%, $(CH_3)_2\ NNH_2$ 50% } Aerozine-50

Engine Parameters*

$A/A^* = 62.5:1$

$D_{exit} = 98.4$ in.

$P_C = 97.0$ psia

**$O/F = 1.6$

Thrust = 20,000 lb $\pm$ 1.0%

Injector System — Unlike-doublet pattern with 15 channels. Mixture ratio variation to be determined.

Nozzle Contour

X	R	
0.000	6.224	Throat — Blend nozzle contour with throat using 6.224 inch radius of curvature. See Figure 3.
3.758	7.487	
7.920	10.575	
11.173	12.872	
15.928	16.000	
20.810	18.941	
25.926	21.764	
31.309	24.492	
35.061	26.264	
40.940	28.856	
45.039	30.544	
51.443	33.009	
55.895	34.611	
60.495	36.178	
65.245	37.711	
70.145	39.208	
75.198	40.668	
80.404	42.091	
85.771	43.475	
91.288	44.826	
94.108	45.477	
99.858	46.761	
105.773	48.002	
111.815	49.202	Exit Plane

*The parameters are subject to change since the vehicle design is in an early phase. In particular, the O/F and the nozzle extension contour are susceptible to variation.

**A tolerance on the nominal O/F is not specified in currently available data.

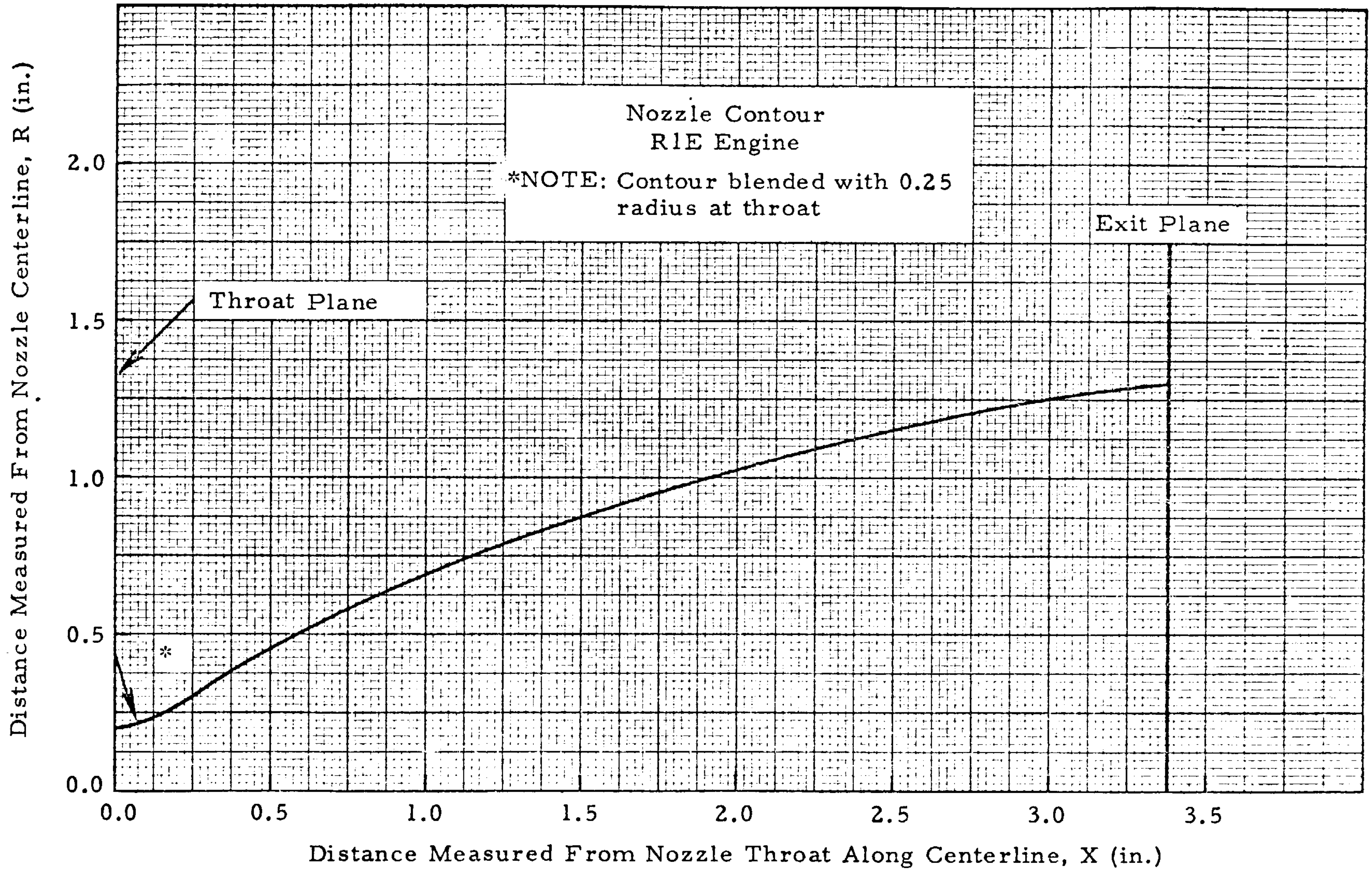

Figure 1 - Nozzle Contour for R1E Engine Used in S-IVB Auxiliary Propulsion System

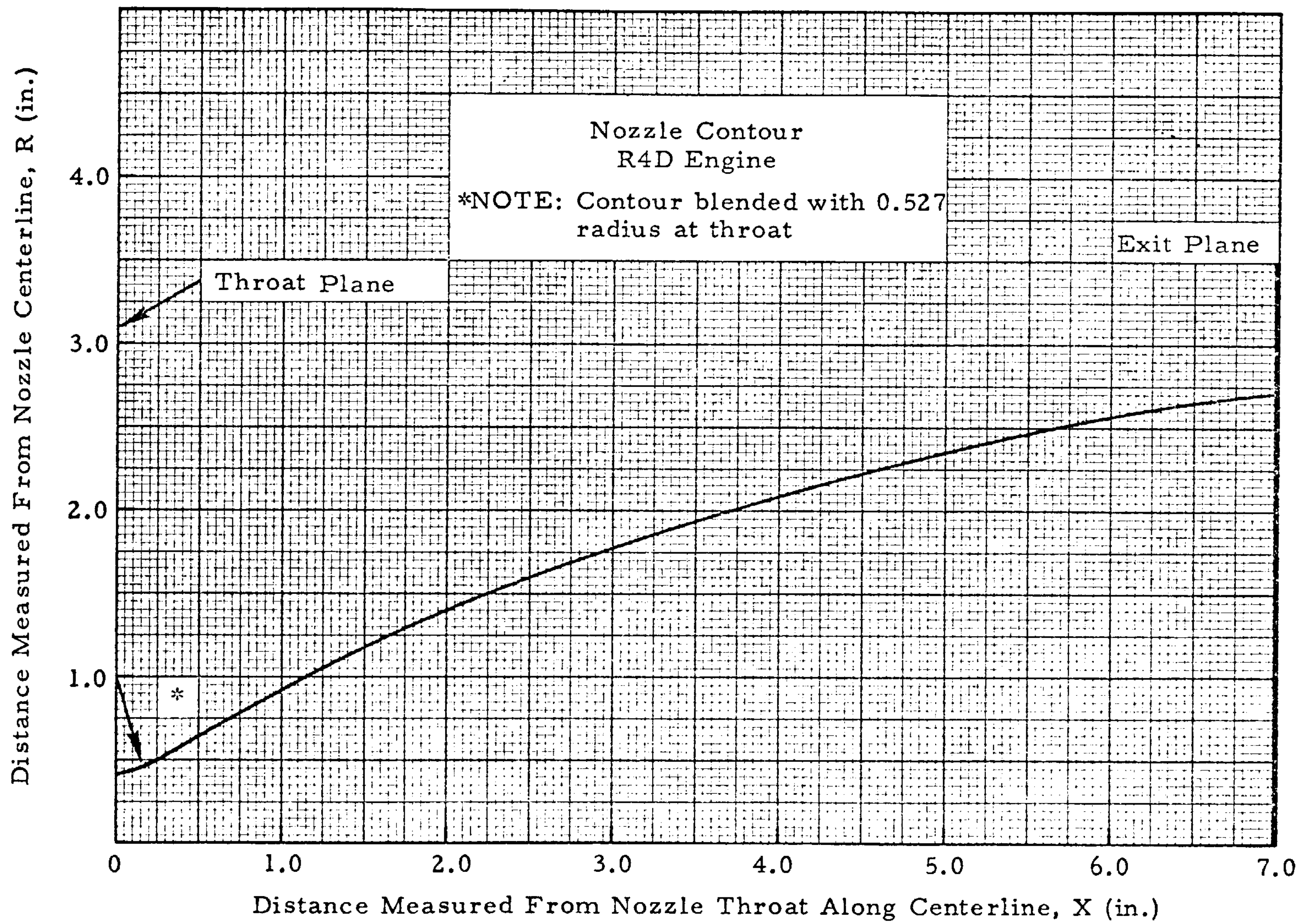

Figure 2 - Nozzle Contour for R4D Engine Used in the Lunar Excursion Module and Command Service Module Reaction Control Systems

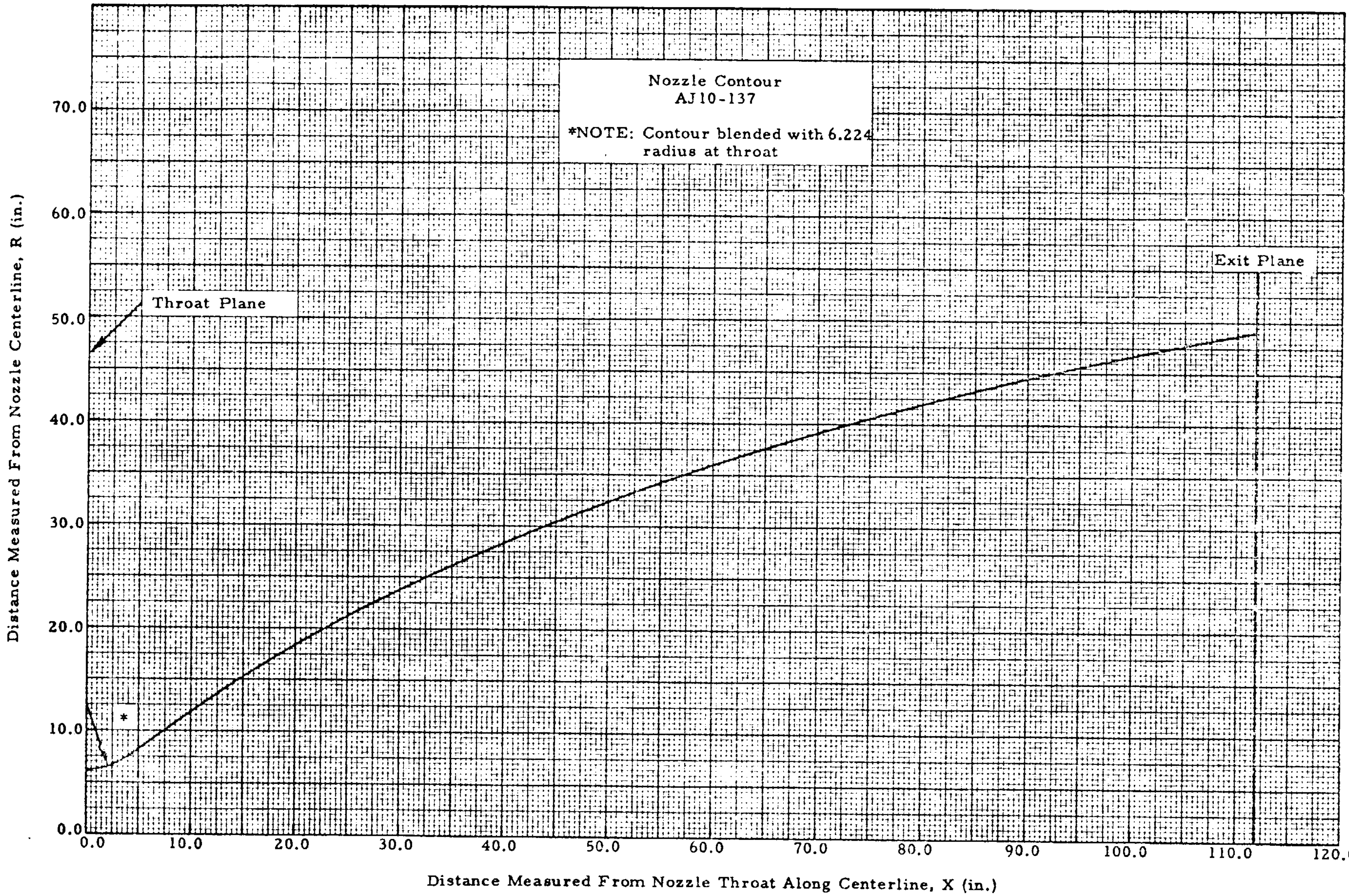

Figure 3 - Nozzle Contour for AJ10-137 Engine Used as Command Service Module Main Propulsion System

Regions (1) and (3) O/F = 0.0, Fuel Film Cooling Flow Constitutes 3.3% of Total Propellant Flow.

Region (2) O/F = 2.06, Main Propellant Flow Constitutes 68.3% of Total Propellant Flow.

Region (4) O/F = 3.0, Pre-igniter Flow, 28.4% of Total Propellant Flow.

NOTE: This O/F variation will be used in calculations to determine the O/F distribution after combustion that will be utilized in the internal and plume flowfield solution.

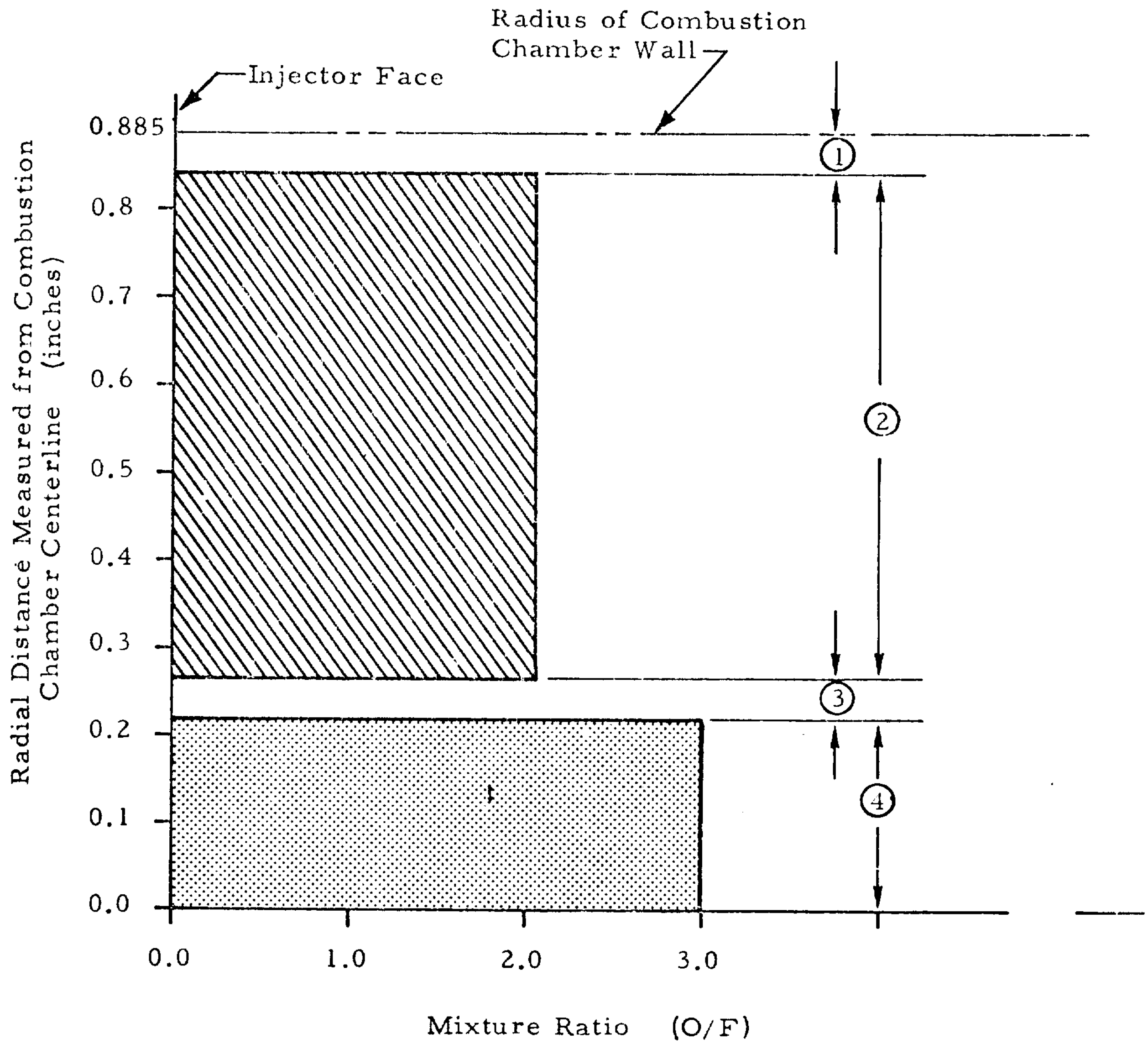

Figure 4 - Mixture Ratio Variation Across Injector Face of R4D Engine Based on Injector Pattern